

DEVELOPMENT, TEST, AND INTEGRATION OF THE AGM-114 HELLFIRE MISSILE
SYSTEM AND FLIR/LASER ON THE H-60 AIRCRAFT

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SUMMARY

The Hellfire Missile System (HMS) and a nose mounted FLIR with laser designator system were selected as integration candidates on H-60 derivatives based on a new fleet weapons requirement. Naval Air Warfare Center Aircraft Division (NAWCAD) Patuxent River conducted ground and flight tests to structurally qualify the HMS and FLIR systems and evaluate their integration into the H-60 airframe. Three ground firings and 45 hours of flight test (including six missile firings and eight launcher jettisons) were conducted in 1995 during the technical feasibility phase and 60 test flight hours were flown in 1997 during the system integration phase. In-flight jettison and missile firing test planning utilized a six degree-of-freedom simulation to develop the minimum number of test points to clear the desired envelope while managing risk. Testing demonstrated the successful structural integration of the HMS and FLIR systems. [CBS2] Testing then proceeded with integration of the functional FLIR and HMS. The integration test program fired 6 missiles at fixed and moving targets, under day and night conditions over land and water using the FLIR/LASER for tracking and autonomous designation. Integration development and testing utilized specialized U.S. Army Hellfire instrumentation as well as the Laser Designator Weapons System Simulator (LDWSS) modeling tool. LDWSS was used to simulate launch conditions and engagement scenarios, predict missile launch transients and trajectories, and identify launch constraint and laser self-designation issues. The simulation tools and test methods employed minimized test flights and required assets, resulting in an efficient certification of this weapon system for fleet use. [CBS3]

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LIST OF SYMBOLS

1. INTRODUCTION

The Left Hand Extended Pylon (LHEP) on the SH-60 was qualified for carriage of gravity dropped stores (fuel tanks, torpedoes, Penguin missile) during the initial aircraft design program. When U.S. Navy fleet requirements dictated that the SH-60 derivative platforms have an additional weapon capability as well as a FLIR capability, the Hellfire Missile System (HMS), along with Commercial-Off-the-Shelf (COTS) FLIR and LASER technologies were identified as candidates for evaluation. Necessary tests were identified to determine the aircraft/system compatibility of a basic FLIR HELLFIRE SYSTEM (FHS) installation prior to proceeding with full system integration. During the technical feasibility/compatibility phase, Naval Air Warfare Center Aircraft Division (NAVAIRWARCENACDIV) Patuxent River conducted ground and flight tests to certify the FHS on SH-60 series airframes with respect to structural compatibility, store safe separation, and safety of flight (reference 1). The integration phase of the program followed with an evolutionary, fully integrated FHS that was evaluated during additional ground and flight tests in both engineering and mission representative environments.

This paper presents an overview of the development, test, and integration of the FHS on the Navy SH-60 aircraft. Discussion of methodology and test techniques is separated into two sections; the technical feasibility phase and the system integration phase. General test results are discussed as well as some comparison between test results and analysis predictions. Usefulness of simulation tools in this aircraft weapon system integration test program is also discussed.

2. DESCRIPTION OF TEST AIRCRAFT AND EQUIPMENT

Two different series SH-60 aircraft were used for the test program. The technical feasibility phase was conducted using a YSH-60F and the

integration phase was conducted on a SH-60B. Except for mission equipment differences and evolutionary upgrades, these two aircraft are approximately the same, with all relevant features such as external stores stations being identical. Additionally, the FHS configuration evolved between the technical feasibility phase and the integration phase.

2.1 SH-60 Aircraft

The U.S. Navy SH-60 Seahawk (Figure 1), manufactured by Sikorsky Aircraft Corporation, is a twin-turbine engine, four bladed single main rotor, and four bladed tail rotor helicopter with an approximate gross weight of 21,500 lbs. The fully articulated titanium spar main rotor has a diameter of 53.7 ft and provides flapping, lead-lag, and feathering degrees of freedom with elastomeric bearings. The four-bladed tail rotor is a rigid system that is canted 20 degrees from the vertical, providing 2.5% of the total lifting force of the main rotor. The aircraft has an irreversible, fully boosted, stability augmented flight control system that includes a controllable stabilator and autopilot to improve pitch attitude and stability. The aircraft has energy absorbing tricycle landing gear and three external stores/weapons stations (two left and one right) that are each equipped with BRU-14 gravity release bomb racks. Two of the stores/weapons stations, right inboard and left inboard, are located adjacent to the fuselage and provide the capability to carry torpedoes and auxiliary fuel tanks. The third station, integrated into the removable LHEP, provides an additional capability for missiles or forward firing ordnance due to its increased distance from the fuselage (approximately 40 inches outboard of the fuselage).

The test aircraft were modified by having a permanent nose mount installed that allowed attachment of the FLIR/LASER mission kit assembly. The LHEP was functionally modified to add MIL-STD-1760 cabling/umbilical for the MIL-STD-1760 Hellfire launcher, a hardpoint for the umbilical emergency jettison disconnect lanyard, and necessary access panels. Additionally, the test aircraft were equipped with instrumentation which included a pitot-static boom mounted on the starboard forward fuselage, flight control position indicators, high

speed film cameras along the port side, strain gages, accelerometers, pressure transducers, thermocouples, and data recording and telemetering equipment.

2.2 FLIR Hellfire System (FHS)

The FHS system used for the technical feasibility phase consisted of the nose mounted FLIR/LASER, the M299 missile launcher, AGM-114 missiles, and the SH-60/Hellfire missile launch test kit (HLTK). The FHS system used for the integration phase replaced the HLTK with the fully integrated Stores Management Unit (SMU) and software, Power Control and Distribution Units (PCU & PDU), and a Hand Control Unit (HCU) for operating the FLIR/LASER. A VCR was also added to record FLIR video and cockpit communication.

FLIR/LASER

The FLIR/LASER consisted of the optical, electronic, and mechanical elements required for thermal imaging, laser ranging/designating, and directing the sensor line-of-sight (LOS). The components were housed in a turret unit (TU) that operated on a two-axis gimbal attached to the nose mount. The second generation FLIR receiver provided thermal imaging by collecting IR scene radiation and converting it into a video signal while the laser range designator (LRD) assembly provided rangefinding and targeting for NATO laser guided munitions such as the Hellfire missile. The TU processor used electronic image stabilization to maintain FLIR image quality in the helicopter vibration environment and the LRD optics contained an image motion compensation mirror designed to maintain FLIR/LRD line-of-sight (LOS) alignment. The TU weighed approximately 114 lbs and was controlled by the FLIR Electronics Unit (EU), separately mounted inside the aircraft cabin. Alignment of the LRD LOS with the FLIR LOS was accomplished prior to flight by attaching a Boresight Module (BM) to the nose mount and rotating the TU to the boresight position. Ground and flight tests during the technical feasibility phase used a non-functioning TU representative of the operational unit in size, weight, and mass moments of inertia.

M299/M272 Hellfire Missile Launcher

The M299 Hellfire Missile Launcher (HML) was an updated version of the M272 launcher used on current U.S. Army and U.S. Marine Corps (USMC) aircraft. The mechanical structure of the M299 (Figure 1) provided a stable platform capable of carrying and rail launching from one to four Hellfire missiles. Unlike the M272, the M299 contained numerous electronics onboard the launcher and had an updated MIL-STD-1760 interface, while increasing launcher weight by only 3 lbs. Empty, the M299 launcher weighed 143.3 lbs, and with four missiles loaded had dimensions of 64 in. long, 22 in. wide, 29 in. tall and weighed 543 lbs. M272 launchers ballasted to the M299 configuration were used for the jettison flight tests as non-recoverable assets. The M299 launcher was used for all captive carriage and live fire flight tests.

The HML's were attached to the aircraft via the BRU-14 bomb rack on the LHEP. The launchers were suspended from two suspension hooks 14 in. apart that engaged two suspension lugs on the top of the launcher hardback. Sway braces on the bomb rack were adjusted against the launcher hardback to prevent lateral movement of the launcher. The MIL-STD-1760 electrical connector of the launcher umbilical was secured to the pylon by an emergency disconnect lanyard that allowed it to separate from the launcher during jettison. The launcher was not capable of independent missile jettison.

AGM-114 Hellfire Missile

The AGM-114 Hellfire missile (Figure 2) is a laser guided missile designed for use against hard point targets. Hellfire can be employed in air-to-air roles against other helicopters; surface-to-surface against armor and ships; and air-to-surface against armor, ships and bunkers. Guidance is provided through automatic terminal homing on the laser signal reflected from a laser designated target. Hellfire uses a shaped charge warhead to defeat individual hard point targets with minimal exposure of the delivery vehicle to hostile fire. The AGM-114 consists of five major sections: seeker, warhead, guidance, propulsion, and control. The AGM-114B model is currently used by the USMC and has an autopilot for low visibility conditions, minimum smoke motor, and a shipboard-qualified safe and arm device (SAD) for the motor. The AGM-

114K model features dual warheads (to defeat reactive armor), an electronic safe arm fuse, electro-optical countermeasures hardening, and an externally programmable guidance section for trajectory shaping/seeker logic changes. The AGM-114K contains both pulse rate frequency and alternate code capabilities. The AGM-114K also contains a shipboard compatible SAD. The AGM-114 weighs 99 lbs, has a diameter of 7 in, and a length of 64 in. Additionally, House Mouse (HM) missiles, developed specifically for the test community, are available to gather various missile system data. The HM missiles are tactical missiles that have the warhead and motor removed, but retain the seeker section. The aircraft system recognizes the HM as a tactical missile. HM missiles can be configured to monitor specific test data parameters such as seeker gimbal angle. This test used production AGM-114B and AGM-114K missiles, production AGM-114B and AGM-114K missiles modified with inert warheads, inert motors, and instrumentation, inert training missiles, dummy missile shapes for emergency jettison tests, and AGM-114 HM's.

Hellfire Launch Test Kit (HLTK)

The HLTK consisted of a Toshiba T6600C lap-top type computer and associated interfaces to the aircraft and launcher. During the technical feasibility, the HLTK was use to control the HMS with minimal electrical integration and interface to the aircraft. The HLTK was capable of controlling and monitoring the launcher and up to 4 missiles. The HLTK provided the following information: master arm status, acquisition mode, launcher and missile Built-In-Test (BIT) in progress and BIT results, missile launch status, primary missile ID, launcher present/absent, launcher safe/armed status, individual launcher rail latch status, missile type, seeker type, missile state, individual missile launch status, and missile away.

Stores Management Unit

The Stores Management Unit (SMU) was designed to monitor, command, and control the M299 Hellfire launcher and the Hellfire missile(s). The SMU was the bus controller for the MIL-STD-1760 weapons bus added to the aircraft; this bus provided the interface between the SMU and the

M299 Hellfire launcher. The weapons bus traffic included command, control, and navigational data for stores and sensors, and the routing of stores information to the FLIR EU for display on the Attack page of the operator's Multi-Function-Display (MFD). The SMU received navigation data via the MIL-STD-1553 avionics bus, command information from the FLIR via the weapons bus, and control inputs via the HCU. The SMU also controlled the fixed missile firing sequence of lower outboard, lower inboard, upper outboard, upper inboard.

3. TECHNICAL FEASIBILITY PHASE

Ground and flight tests acquired aircraft compatibility data as part of the structural and safe separation evaluation of the FHS on the SH-60. Ground tests consisted of a static pull test, Ground Vibration Tests (GVT), electrical checks, EMC evaluation, and ground missile firings. These tests were designed to provide enough information to evaluate concept feasibility prior to proceeding with the flight tests. Flight tests consisted of captive carriage, launcher jettisons, and missile firings requiring approximately 45 flight hours. Results of the technical feasibility phase were used to make a recommendation for proceeding with the integration phase.

3.1 Ground Tests

3.1.1 Proof Load Test of FLIR Support Structure

In order to verify the structural adequacy of the FLIR nose mount, a static proof test was conducted. A load of 1534 lbs (115 % maximum expected load during in-flight/landing operations) was applied at the CG of the FLIR shape using a hand operated hydraulic actuator and a load cell. Output of the FLIR support structure strain gages was recorded and monitored during the test. The proof load was applied in 10% increments up to 1534 lbs. Input load measured by the load cell was simultaneously recorded with the strain gage output.

3.1.2 Ground Vibration Tests (GVT)

GVT were performed to determine the natural structural frequencies of the FLIR mount and Hellfire Missile Launcher (HML) installations on the aircraft; the natural frequencies were then compared with the major aircraft forcing frequencies to identify potential vibration related structural problems prior to flight test. Vibration characteristics of the two installations were determined by using an impulse hammer and a random input shaker method. For both methods, a stationary excitation point and roving accelerometer approach were used to apply and measure the inputs and measure the response characteristics. The output data was processed with a Fast Fourier Transform (FFT) analyzer and plotted as transfer functions. The structures were excited with random vibration separately in lateral, vertical and longitudinal directions with various missile and adjacent store combinations. Potential resonances evident in the transfer function were compared to the aircraft forcing frequencies to determine if a ten percent frequency separation was present to preclude the potential for mechanical instabilities and resulting high vibratory stress levels in flight. The required separation was not demonstrated for the HML with 4 missiles loaded. Specifically, a small 17.1 to 17.3 hz vertical mode was observed which could possibly be excited by the aircraft 4x main rotor frequency of 17.2 Hz at 100 percent Nr. Subsequent ground tests with the rotors engaged produced a maximum overall vibratory level of 1.3 g's which was within the range of previous data obtained for similar, structurally acceptable installations on the LHEP, thus allowing progression to captive carriage flight tests.

3.1.3 Ground Missile Firing Tests

Three ground missile firings were conducted from the aircraft to determine the HMS compatibility with the LHEP and surrounding aircraft structure. Stress, vibration, thermal, pressure, and store/aircraft separation data were acquired during each missile launch. The helicopter was positioned 7° nose-up on a platform 44 inches above ground level with the LHEP extending over the edge, providing approximately 50 inches of lower missile to ground clearance and minimum rocket motor blast ground reflections. One missile was fired from the upper inboard station, the lower inboard station, and the

lower outboard station in the Lock-On Before Launch (LOBL) mode. The missile impact zone was determined by a floating target approximately 3500 meters downrange illuminated by a shore based laser designator. Located next to the laser designator was a laser spot video system capable of displaying the laser energy on the target. Additionally, seeker azimuth and elevation angles were monitored to ascertain accurate missile lock on the target prior to launch.

Aircraft Structure Compatibility

Stress/strain data were incorporated into the aircraft NASTRAN model for component life cycle fatigue predictions. Pressure and thermal (missile plume) data were gathered to verify that overpressure and heat from the rocket motor blast would not adversely affect port side external aircraft features. Maximum temperatures of 480 degrees F were observed on the port auxiliary fuel tank skin, but had a short duration of .2 seconds during the launch transient. Ground firing tests without rotor wash and forward airspeed resulted in worst case temperatures. The missile temperature plume during ground firing tests was concluded to be benign and not considered a significant risk factor prior to flight tests.

Separation Characteristics

Along with the structural compatibility of the HMS, the separation characteristics of the missile leaving the HML were determined during the ground firings. Pylon flex, missile tip-off angles, missile tip-off rates, missile/aircraft/adjacent store clearances, rotor blade clearance, and missile trajectory information were recorded. Data was analyzed to ensure that the missile did not come too close to any part of the aircraft structure and that the aircraft dynamic structural response to missile firing loads would not put the missile outside of its launch constraints envelope. Ten surveyed, high-speed (400 fps) film cameras with Interservice Range Instrumentation Group (IRIG) time stamping documented each missile firing. The three onboard cameras (two forward and one aft of the launcher) were also operated during

each firing. Camera data provided immediate qualitative information and was post-processed to calculate a 13 camera photogrammetric launch trajectory solution prior to flight tests. Each missile exhibited safe separation characteristics with respect to the airframe and the rotor disk as it traveled down the launch rail and away from the aircraft

Two of the missile firings were conducted with missiles that had angular rate gyros installed in the inert warhead section to measure dynamic response of the launcher and launch transients imparted to the missiles. During launch, pitch, roll, and yaw rate data were recorded as the missile traveled along and off the rail. Data were recorded until the approximately twenty foot long breakaway aircraft/missile umbilical was pulled away from the aircraft. Analysis of these data indicated that the AGM-114 missile experienced no adverse effects when ground launched from the LHEP of the SH-60.

3.2 Flight Tests

3.2.1 Captive Carriage Flight Tests

Thirteen captive carriage flights were conducted to assess the structural impact of the FHS on the SH-60 airframe/LHEP and to evaluate any changes in flying qualities and performance (FQ&P). Various HML missile load configurations were used during dynamic engineering tests and mission related maneuvering flight. In addition to the aircraft instrumentation, one of the inert missiles carried a rate gyro package in the warhead section, one missile was instrumented externally with accelerometers, and the HML was instrumented with accelerometers. Limited telemetry capability was provided on the test aircraft to allow real-time monitoring of critical parameters by engineers on the ground

Analysis of structural loads and vibration data with FHS installed concluded that integrity of the SH-60 airframe and operability of the FHS would not be adversely affected during typical mission maneuvers. Structural strain data was less than 10% of allowable levels. There was no degradation in flying qualities or performance of the SH-60 configured with the FHS as compared to the SH-60 configured with a 120

gallon auxiliary fuel tank on the port inboard station, Mk 50 torpedo on the port outboard station, and Mk 50 torpedo on the starboard inboard station. Minimum clearance between the ground and the M299 launcher was also evaluated during vertical landings up to a maximum Rate of Descent (ROD) of 12 ft/sec. No significant launcher to ground clearance issues were observed. The vertical landing data was used to extrapolate and model lower missile/flight deck clearances in the dynamic shipboard environment in support of ship approach envelope development.

3.2.2 Jettison Flight Tests

Prior to test, a jettison analysis (6 DOF computer simulation, reference 2) was performed to define the jettison characteristics of the HML for use in determining the jettison flight test matrix. The analysis also determined the launcher loading which exhibited the worst case jettison characteristics in terms of minimum aircraft clearance, and the effects of helicopter sideslip and rate of descent. The analysis predicted that the launcher loaded with two missiles, on the upper and lower inboard stations, was worst case. The analysis concluded that the dominant variable affecting movement of the store toward the aircraft was sideslip and that aircraft descent rate would not significantly affect store jettison characteristics. Results of the analysis predicted store/aircraft contact would occur (missile nose with aircraft main mount tire) at a sideslip of -5° with a forward airspeed of 80 KCAS.

Eight flights were then dedicated to the jettison of the HML in level flight and autorotative descents. The HML was loaded in the predicted worst case configuration and mass properties were verified to be within the limits of reference 3 for separation testing. The launcher umbilical was connected for all jettisons so that all standard configuration separation forces were present at release. Jettison test flight conditions are presented in Table 1. Onboard high-speed (200 fps) 16mm film cameras and a safety chase helicopter with onboard photographer documented each jettison. Safe separation characteristics of the missile/launcher combination were reviewed with respect to

aircraft/launcher clearances and compared with the trajectories predicted by reference 2. Film data from the three onboard cameras were used to calculate a photogrammetric solution of the store's trajectory and pitch, roll, and yaw motion about its CG.

The first four test points were conducted with excellent separation characteristics. Review of onboard and chase film data and the photogrammetric analysis from the first four points showed the launcher/missile store combination falling straight down and away from the aircraft, with stable separation characteristics. Since the first four jettison tests indicated that the jettison analysis was conservative, jettison test points five thru eight were flown with a more aggressive build-up (see, table 1) to gather separation data over a less restrictive, more fleet representative envelope. Separation characteristics for test points 5 thru 8 were still excellent; the store exhibited stable characteristics, falling straight down and away from the aircraft. General store motion for all eight jettisons was characterized by clockwise roll (view from aft), pitch up, and left yaw well clear of the aircraft. Higher initial roll rates were observed during the 3000 fpm ROD test points. Figure 3 presents the 3 camera, 6 DOF photogrammetric solution of the first jettison test point.

TABLE 1
JETTISON TESTS AND TEST CONDITIONS

Test Pt.	Airspeed (KCAS)	Rate of Descent (ft/min)	Sideslip (Ball position)
1	60 KCAS	0	+1.5° (1/4 RT BALL)
2	100 KCAS	50	-1.0° (1/4 RT BALL)
3	80 KCAS	0	-2.0° (BALL CNTR)
4	85 KCAS	0	-6.0° (1/4 LT BALL)
5	82 KCAS	1000	-5.0° (1/4 LT BALL)
6	78 KCAS	1500	-7.0° (BALL CNTR)
7	82 KCAS	3000 (Full Auto)	-7.0° (BALL CNTR)
8	80 KCAS	3000 (Full Auto)	-8.0° (BALL CNTR)

Jettison test data were simultaneously provided to the U.S. Army Rotary Wing Stores Integration (RWSI) project office for validation of the RWSI store separation prediction software. Comparison of the flight test data with the RWSI predictions is reported in reference 4. General conclusion was that the RWSI software satisfactorily demonstrated its potential as an engineering tool for predicting store

separation characteristics, but needed additional data from other helicopter separation programs to help refine the prediction accuracy of the store's pitch and yaw motion.

The in-flight jettison tests demonstrated the capability to successfully jettison the HML/missile store combination from the LHEP on Naval SH-60 series aircraft under the conditions tested. Since the launcher configuration tested was deemed to be the worst case, it may be assumed that other launcher load configurations have as good or better separation characteristics under the same flight conditions. The flight conditions tested were used as the basis for the emergency jettison envelope developed for fleet use.

3.2.3 In-flight Missile Firing Tests

With preliminary analysis of the ground firing separation data indicating that it was safe to proceed, three in-flight missile firings were conducted from the aircraft to further evaluate the HMS compatibility with the LHEP and aircraft structures. Aircraft handling qualities and performance were also evaluated during launch. One missile was fired from the lower outboard station with the aircraft in a hover, one missile from the lower inboard station with the aircraft at 100 KIAS, and one missile from the upper outboard station with the aircraft at 135 KIAS. The missiles were launched from the aircraft in LOBL mode at a floating target, approximately 4500 meters offshore, that was illuminated by a shore based laser designator. Prior to test the missiles' mass properties (weight, CG, and moments of inertia) were checked against those of unmodified AGM-114B missiles in accordance with reference 3. The test aircraft was inspected before and after each in-flight firing to monitor external structural integrity of the aircraft.

Aircraft Structure Compatibility

Aircraft structure compatibility was evaluated during in-flight missile firing tests using the same instrumentation as the ground tests.

Accelerometer data, missile overpressure data, and aircraft structures' strain data were provided to Sikorsky for analysis. Maximum temperature of 140° F on aux tank skin was observed during the lower inboard firing. There were no noticeable effects on the port side aircraft, launcher, or LHEP surfaces due to the missile firings. Firing of the Hellfire missile was deemed to be compatible with the SH-60 aircraft structure.

Separation Characteristics

Along with the structural compatibility of the HMS, the separation characteristics of the missile leaving the M299 launcher were further evaluated during the inflight firings. Prior to test, a safe separation and tip-off analysis, reference 5, concluded that safe separation would occur within the entire boundary of the SH-60 flight envelope. Pylon flex, missile tip-off characteristics, clearance between the missile, aircraft, and adjacent stores, rotor blade clearance, and missile trajectory were again recorded during the test events. The three onboard cameras along with a safety chase helicopter with an onboard photographer provided 35mm still photos and 16mm high-speed film coverage. Camera data provided immediate qualitative information and was post-processed to calculate a 3 camera photogrammetric solution.. Each missile exhibited safe separation characteristics with respect to the airframe and the rotor disk as it traveled down the launch rail and away from the aircraft.

4. INTEGRATION PHASE

Once the technical feasibility phase and FLIR integration had been satisfactory completed, the next objective was to develop an initial firing envelope for the Rapid Deployment FLIR Hellfire System on the SH-60B and to evaluate the Rapid Deployment FLIR Hellfire System helicopter's ability to passively detect, classify, identify, track, and attack surface targets. For this test effort, missile availability was a limiting factor, five AGM-114B's and 1 AGM-114K missiles were available to evaluate total system integration. To supplement testing,

Laser Designator Weapon System Simulation (LDWSS), a simulation model developed by the US Army's Missile Command (MICOM), was used to establish an initial aircraft firing envelope. LDWSS is a high fidelity simulation model used by the US Army to determine probability of hit (Ph) and probability of kill (Pk) for varying targets and conditions. LDWSS was updated for the Naval application, including boat/ship targets, target motion/ship response as a function of sea state, and laser characteristics in the ocean environment. Data gathered through this test program was used to verify LDWSS and to create fleet training scenarios.

A captive carry flight test program was established to gather data needed to update the model. Factors accounted for in the LDWSS model that needed to be updated were autotracker robustness, laser energy and laser energy distribution, aircraft pitch and yaw reference angles, and overwater environmental factors. Laser energy data was collected during two separate flight test programs. The first measured laser energy with respect to energy distribution, laser jitter, and laser boresight accuracy. The second portion of laser energy testing measured laser energy in an overwater environment. This test also evaluated how water affected laser energy. It looked at laser energy absorption, energy reflected back to and away from the designator, and salt spray effects on the laser as it left the designator. Pitch and yaw reference angles between the aircraft and missile were also measured and input into the model. This was the first time environmental data for the overwater environment had been gathered for the LDWSS model

4.1 Updating the Model

Automatic Video Tracker Testing

Flight tests was conducted against ships and/or the selected target to determine the automatic video tracker (AVT) performance in both centroid and correlation modes while operating in the flight environment from 50 ft AGL to 1000 ft MSL at 0 to 150 KIAS. The aircraft was vectored to the target by controllers on a straight and level approach and positioned at an altitude, range, and airspeed

specified in table 2. Once test conditions were established the system operator centered the FLIR reticle on the target, optimized the FLIR image, ensured the on-board video was recording with IRIG B time on, selected CENTROID (or POINT) TRACK MODE, and depressed and held the AVT track button until a track was established. Pertinent AVT track qualities including track stability were then recorded. Throughout the inbound run, the operator qualitatively assessed the offset track function by selecting offset track, slewing the reticle off-axis in all directions at the extreme edges of offset track, releasing offset track to return the reticle to the center of the track position, and then attempting to place the reticle over a specific spot on the target and stabilize. During 200 ft altitude or above run-ins, the aircraft banked left/right, up to 30°/sec (in increments of 10°/sec), up to 45° AOB for 90° heading change, held 90 degree heading change momentarily then banked left/right, up to 30°/sec (in increments of 10°/sec), up to 45° AOB for 90° heading change to return to the inbound course. During 50 ft altitude run-in points, the aircraft approached the target with wings level. During any test if track was lost, the bank angle was reduced until track could be maintained. The entire test matrix was repeated with correlation (or AREA) TRACK MODE selected.

Table 2. Automatic Video Tracker Test Points

Test Point	Altitude (Ft.) (AGL)	Air Speed (KIAS)	Approx. Initial Slant Range (Ft/Km)
1	50/200/1000	70-80	62,336/19
2	50/200/1000	70-80	62,336/19
3	50/200/1000	100-120	62,336/19
4	50/200/1000	100-120	62,336/19
5	50/200/1000	70-80	124,672/38
6	50/200/1000	70-80	124,672/38
7	50/200/1000	100-120	124,672/38
8	50/200/1000	100-120	124,672/38

Inflight Laser Characteristics Testing

Flight tests was conducted against the Electro-Optical Thermal Target (EOTT) to determine the boresight offset (if any) between the FLIR and LRD in flight. The EOTT panels were heated to their maximum ΔT 's to improve recognition. The aircraft was in constant communication with controllers for proper flight path guidance. The aircraft was vectored to a preselected bearing from the EOTT and was positioned at the first altitude, range, and bearing angle described in table 3. Once test conditions were established the system operator centered the FLIR reticle on the EOTT, optimized the FLIR image, and ensured the on-board video was recording with IRIG B time on. During each test event ground personnel recorded laser spot video, time stamped with IRIG B time using Laser Airborne Targeting System (LATS). This was repeated for each altitude, range, and bearing angle in table 3.

Table 3. Inflight Laser Characteristics Test Points

Test Point	Altitude (Ft. AGL)	Ground Range (Ft.)	Slant Range (Ft.)	FLIR to Aircraft Relative Bearing (degrees)
1	1,050	3,100	3,300	0, 90, 270
2	3,200	15,900	16,200	0, 90, 270
3	5,100	25,750	26,250	0, 90, 270
4	6,000	30,100	30,700	0, 90, 270
5	10,000	55,000	56,000	0, 90, 270

Overwater Laser Characterization Tests

In order to evaluate laser energy behavior in an overwater environment a 8.5 flight hour test program was established. This involved the test aircraft lasing the target while a UH-1H helicopter equipped with a U.S. Army developed Hellfire instrumentation package consisting of a modified Hellfire missile seeker head that monitored reflected laser energy and a recording system. Test conditions are presented in table 4. Both aircraft were equipped with Mid Atlantic Tracking System (MATS) for proper positioning throughout the test by range control. The target boat, a 56 ft range boat, was also MATS equipped. With the test aircraft lasing the range boat, the UH-1H flew missile level

flight profiles from 100 to 1900 ft AGL, in 200 ft increments, collecting laser energy data between 7 and 1 km. To collect data regarding possible laser energy reflected from the water at various grazing angles, laser data was collected onboard the UH-1H while hovering at 1, 0.5 and 0.1 km at altitudes from 100 to 900 ft AGL with the test aircraft lasing long, short, at the waterline, and aft of the target boat. The test aircraft was again at a range of 4 to 8 km and an altitude of 50 to 500 ft AGL. Prior to performing over-water testing with the UH-1H, the test aircraft directly lased the EOTT while the UH-1H flew the same level flight profiles collecting laser data for reference and equipment checkout.

Table 4. Over-Water Laser Characterization Tests

EVENT	SH-60 AIRSPEED (KIAS)	SH-60 ALTITUDE (FT AGL)	RANGE (KM)	SH-60 PROCEDURES
1	60 - 90	1000	10-4	1. Fly straight and level inbound to target beginning at 10 km. 2. Lase target every 1 km checking for missile seeker lock-on. 3. Investigate effect of salt environment on laser emissions.
2	60 - 90	500	10-4	
3	60 - 90	200	10-4	
4	60 - 90	50	10-4	
5	60 - 90	50 - 500	8 - 6 and 6 - 4	1. Fly multiple racetrack patterns with inbound legs as listed under target range until UH-1H has covered entire inbound leg at given altitude. 2. Position laser spot for optimal energy return.
6	60 - 90	50 - 500	8 - 6 and 6 - 4	1. Fly racetrack pattern with inbound legs as listed under target range. 2. Lase tgt adjusting laser spot as coordinated with UH-1H to lase short, long, at the waterline, and aft of the target boat.

Pitch and Yaw Reference Study

To establish minimum launch altitudes and to help determine missile launch constraints and inhibits in pitch and yaw, aircraft data in the form of pitch and yaw reference angles, between aircraft centerline and

missile centerline, were acquired. Also, electronic pitch reference signal voltage accuracy was verified. To accomplish this, launcher rail angles with respect to aircraft centerline, both average and worst case by intentionally hanging the launcher in an improper manner, were measured. This data was input into the simulation to determine its effect on missile trajectory. These initial condition launch parameters were necessary for the simulation to fly the missile along the proper trajectory for acquiring the desired target. Minimum launch altitudes were then established using the LDWSS model once this data had been incorporated.

Environmental Data

Meteorological conditions in the atmosphere are an important factor in calculating laser transmission from the designator to the target and laser energy returned to the missile seeker. The amount of energy that is totally intercepted by the missile as well as the laser beam divergence along the line of sight path for an overwater environment needed to be quantified. As described in Reference (6) the air turbulence factors in an overwater environment are strongly driven by the air-sea temperature difference, and to a lesser extent by wind speed, humidity, and other meteorological factors. In general, air turbulence is highest during the day, falls to a minimum in early evening as the air cools to the water temperature, and then increases somewhat late at night as the air cools below the water temperature. Reference 6 provided us with the necessary data to predict laser beam spread and laser energy transmission over the ocean. The original LDWSS model used three values of air turbulence characterized as low, moderate, and high. Those three values were adjusted in the Naval version of the model to represent low, medium, and high turbulence that would be expected in the overwater environment.

4.2 Live Fire Tests

The first test event took place at Eglin AFB's C-7 test range. The C-7 test range was a land range specific instrumented for Hellfire testing. For this live fire event, high-speed video of the missile was taken

from launch to impact. High-speed film (aircraft mounted cameras) of the missile leaving the rail were also taken. A ground-mounted silicon vidicon camera was slewed to the target to verify target illumination before missile launch. Time Space Positioning Information (TSPI) data was taken of the aircraft to document exact slant range to the target at missile launch. Throughout the flight path, TSPI data of the missile was also taken. TSPI data of the missile allowed for detection of an inflight missile failure (missile failure flight path was known). The target for this event was a stationary M-60 tank hulk. Next, four modified AGM-114B's and one modified AGM-114K missile were fired to assess the system performance in a water environment. These missiles were modified by having the warheads removed and inert mass added to the warhead section to simulate the weight, cg, and moment of inertia of a production missile. This modification was conducted in an attempt to not destroy the target. The target for the overwater events was a 56 ft QST-35 target boat modified to represent a PBI patrol boat. Target speed began at minimum steerage and built up to maximum remote controlled speed, approximately 25 kts. High-speed film cameras were placed on the target to record missile impact. All shots were conducted in the Lock-On-After-Launch Direct mode. Prior to each event, a Ph value was calculated using the updated LDWSS model. The first over-water shot mirrored the overland shot as close as conditions would allow. The remaining 4 events were used to verify system performance at various points of the missile firing envelope by varying airspeed, range, target speed, and laser delay times.

4.3 Integration Phase Summary

Because of test asset limitations it was impossible to establish a realistic firing envelope by missile firing alone. Therefore, a test program that updated the existing LDWSS model in combination with limited missile firings was established. The LDWSS model was used to establish the initial live firing matrix for this test program and evaluate other scenarios not tested. This tool was successfully used to identify launch constraint and laser self-designation issues, develop

employment and tactics, conduct test hazard analyses, and manage technical risk during system development. Efforts are currently underway to update the target data base to include naval targets to use LDWSS to develop cockpit cards that would include tactical information for use by aircrews.

5. ELECTROMAGNETIC COMPATIBILITY (EMC)

An EMC evaluation of the FHS was performed to ensure compatibility with aircraft systems and to identify problems with vulnerability to electromagnetic radiation in the local flight test area and in the fleet environment. An HM missile was used during the EMC evaluation. EMC evaluations were conducted with an HM missile and a M299 launcher installed. Tests were conducted with the missile in the loaded, armed, and ready to launch modes. No intrasystem Electromagnetic Interference (EMI) was noted in either the SH-60 equipment or Hellfire missile and M299 launcher. Additionally, previous Hellfire missile intersystem EMC testing on other platforms, including the AH-64D Longbow system, was reviewed. EMC testing to evaluate compatibility with the shipboard environment was also conducted. All systems operated satisfactorily during this testing.

6. CONCLUSIONS

During the technical feasibility phase, 6 DOF separation models were used to develop test matrices while managing technical and program risk. Flight tests were then conducted and refined based on results and their comparison to simulation predictions. The result was completion of the flight test program using minimal ordnance assets. The integration phase followed a similar approach by using LDWSS and specialized instrumentation that enabled a complete evaluation of the integrated system with a minimum number of missile firings.

Development, test, and integration of the HMS and FLIR/LASER on the SH-60 greatly benefited from the use of computer simulation as an engineering tool. Certification of the FHS on the SH-60 was successfully completed using a two phase program approach. Technical

feasibility and system integration testing used simulation tools along with traditional flight test methods to efficiently certify this weapon system for fleet use.

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